

# NEW DEFINITIONS OF KINETIC VISUAL ACUITY AND KINETIC VISUAL FIELD AND THEIR AGING EFFECTS

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When statistically analyzing the age groups of traffic accident fatalities, senior citizens account for over 50% of all deaths. Similarly, over 50% of all fatalities occur at intersections. In light of this, research on human behavioral traits, kinetic visual acuity, kinetic visual fields and their aging effects is eagerly sought to uncover the causes of traffic accidents. When renewing their driver's license, senior citizens undergo a kinetic visual acuity test during their class to determine their driving aptitude.

However, traditional kinetic visual acuity and kinetic visual field measurements do not factor in the effects of individual differences in simple reaction times. This study identifies problems with the traditional method employed to define kinetic visual acuity and kinetic visual fields, and proposes new definitions of kinetic visual acuity and kinetic visual fields that measure simple reaction times and their aging effects. Simple reaction time tests reveal that simple reaction times of senior citizens are longer than those of younger people. The results of appraisal tests between traditional and new kinetic visual acuity definitions demonstrate the appropriateness of the new kinetic visual acuity definition. The study also takes a quantitative look at the aging effects of kinetic visual fields, measuring kinetic visual field characteristics of senior citizens while assessing space dependence, light dependence and index speed dependence of young people. The results obtained show that kinetic visual field ranges decrease with age, particularly in upward visual fields rather than downward visual fields in all target conditions. Visual field angle reductions in the temple sides of upward visual fields were of particular note.

**Key Words:** Kinetic visual acuity, Kinetic visual field, Aging effects, Reaction time, Traffic safety

## 1. INTRODUCTION

In recent years, senior citizens account for over 50% of all traffic fatalities, and accident location analysis reveals that over 50% of fatal traffic accidents occur at intersections. One conceivable reason for the high rate of fatal traffic accidents at intersections and in their vicinities, and the high percentage of senior citizen deaths, is their relationship with basic vision properties, kinetic visual acuity and kinetic visual field recognition properties.

Kinetic visual acuity is the ability to identify moving objects. The ability to identify objects moving horizontally or vertically is called *dynamic visual acuity* (DVA)<sup>1,2</sup>, while the ability to identify approaching objects is called *kinetic visual acuity* (KVA)<sup>3,4</sup>. In sports such as baseball that involve many horizontal and vertical movements, DVA is often used. When driving an automobile, however, drivers often must recognize signs moving forward and backward, requiring the use of KVA

for traffic safety. In Western countries, visual acuity for moving objects is uniformly referred to as DVA. KVA is a concept introduced by Japan. Traffic safety education and such have always used kinetic visual acuity test apparatuses primarily to measure KVA. A static visual acuity of at least 0.7 is required to receive a driver's license. Static visual acuity is the ability to recognize still objects. However, sometimes kinetic visual acuity weakens even with good static visual acuity. When people age, their KVA weakens, contributing to the high rate of senior citizen traffic fatalities. Due to this, senior citizens are now required to attend a class when renewing their driver's licenses. In this class they undergo a *KVA test* to determine their *driving aptitude*.

Kinetic visual field refers to the visual range in which a moving target can be seen. Peripheral vision information is important in traffic environments. The amount of that information that can be obtained plays an important role, making peripheral vision width a major

factor. Research on kinetic visual fields for obtaining peripheral vision information, along with their aging effects, is an important area of study. Prior studies<sup>2,3</sup> on kinetic visual field measurements have reported such findings as the larger the target size and the greater the brightness, the wider the kinetic visual field area<sup>5,6</sup>, and in single-eye kinetic visual field measurements there are no area differences between the left eye and the right eye.

However, past research and commercially available kinetic visual acuity and kinetic visual field measurements did not take into account individual differences in the reaction times of subjects whose kinetic visual acuities and kinetic perimeters were being tested from the time they identified targets to the time they responded. Measuring kinetic visual acuity and kinetic visual fields without taking into account simple reaction times is problematic in that it mixes the evaluations of human visual performance with behavior performance. In order to solve the problems of past studies and present medical apparatuses, this study redefines kinetic visual acuity and kinetic visual field, measuring simple reaction times of young persons and senior citizens to take into account individual differences in human simple reaction times. It also investigates the aging effects of kinetic visual acuity and kinetic visual field properties.

## 2. SIMPLE REACTION TIME AGING EFFECTS

Humans make decisions and take appropriate action upon seeing external stimuli. The time required to make a decision is referred to as judgment time, while reaction time refers to the time it takes to begin acting after a stimulus is presented. Judgment times are very short when reacting to simple stimuli; reaction time in these situations is referred to as *simple reaction time* (SRT). Simple reaction times do not rely on recognition and judgment differences, and can be thought of as human behavioral traits. We will now use an experiment to take a quantitative look at the effect aging has on simple reaction times.

### 2.1 Experiment method

Subjects were 87 healthy males in their 20's - 90's (20's: 9, 30's: 6, 40's: 4, 50's: 3, 60's: 6, 70's: 26, 80's: 28, 90's: 5) with no eye disorders.

A round black target of sufficient size is shown in the middle of the screen for a period of one second as a visual stimulus. Subjects watch the center of the screen while holding a response button, which they press the instant they see the target. The target is shown ten times at 2 - 4 second randomly determined time intervals. The

time it takes a subject to press the response button after a target is shown is measured as the individual's simple reaction time. The apparatus developed by the authors in past research was used in this experiment<sup>7</sup>.

### 2.2 Experiment results and considerations

The experiment results of the 87 subjects are shown in Figure 1. The graph's horizontal axis represents the subject age groups, while its vertical axis and the numbers in the graph are the average simple reaction times recorded for each age group. The error bars indicate standard deviation. Simple reaction times for subjects in their 20's, 30's, 40's and 50's were within 200 ms - 300 ms and showed little deviation. However, subjects in their 60's and older displayed differences of over 100 ms. This indicates there is a considerable delay in the reflexes of senior citizens. Using one-way analysis of variance to appraise the aging effect on reflexes showed significant results:  $F(7, 86) = 7.56$ ,  $P < 0.001$ . Further, linear contrast test results showed an increase in motion times accompanying increases in age ( $F(1, 86) = 46.74$ ,  $P < 0.001$ ). Using a multiple comparison test to compare simple reaction times between age groups showed no significant combinations in 20's - 50's age groups. Thus, while no significant differences were observed in the 20's - 50's age groups, motion times significantly slowed from the 60's and older groups. Furthermore, as the error bars indicate there was far more individual deviation in the older age groups (70's and older) than that witnessed in the younger groups (40's and younger).

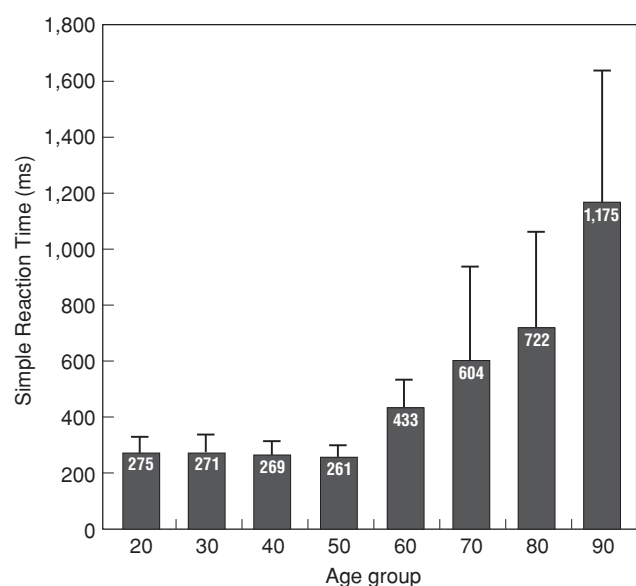


Fig. 1 Simple reaction time experiment results

The above test results demonstrate that the aging effect of reflexes plays a major role. This effect has a major impact on the KVA and kinetic visual fields of senior citizens in particular. Past research and commercially available kinetic visual acuity and kinetic perimeter apparatuses did not take into account the above individual differences in the reaction times of subjects and aging effects. Hence, kinetic visual acuity and kinetic visual fields, acting as indicators that assess human visual perception functions, include behavioral traits, leaving the issue of inaccuracy unresolved.

### 3. NEW DEFINITIONS OF KINETIC VISUAL ACUITY AND KINETIC VISUAL FIELDS

KVA uses the same target (Landolt ring) as in static visual acuity, measuring the size of the target seen as it approaches the subject from a distance at a fixed speed. Reactions of tests employing traditional KVA test apparatuses involved pushing the reaction lever down in the direction the gap in the Landolt ring is facing. However, as discussed in chapter 2 this does not take into account individual differences in simple reaction times and aging effects. This study proposes new definitions for kinetic visual acuity and kinetic visual fields that take into account individual differences in simple reaction times in order to accurately assess human visual perception functions.

We will now explain the new definition method for kinetic visual acuity and kinetic visual field using the kinetic visual acuity illustrated in Figure 2 as an example.  $t_s$ ,  $t_c$  and  $t_r$  in Figure 2 represent the time the target begins to be shown, the time it is perceived, and the reaction

time, respectively. CT (consciousness time) is the time the target is perceived ( $CT = t_c - t_s$ ), SRT (simple reaction time) is the time it takes to react to the target upon perception ( $SRT = t_r - t_c$ ), and RT (reaction time) is the total time it takes to react to the target ( $RT = t_r - t_s$ ). As in Figure 2, traditional KVA measurements were defined by the static visual acuity corresponding to the size of the target at the time of reaction time ( $t_r$ ). For example, when moving the target at a fixed speed from a distant location corresponding to a KVA of 1.5 to a forward facing location corresponding to a KVA of 0.1, the location at which the subject accurately recognizes the moving target is designated as  $t_c$ . The KVA at that time is 0.5, which is the subject's true KVA. However, by the time the subject reacts the target moves to the  $t_r$  location, which results in a tested KVA value of 0.1 for the subject. The subject's true KVA is 0.5, not 0.1. This test result inaccuracy is the problem with the traditional definition method. In Figure 2, the reaction time (RT) includes both the consciousness time (CT) and the simple reaction time (SRT). Simple reaction time is the time it took from the time the target is perceived ( $t_c$ ) until the reaction action is finished ( $t_r$ ). Simple reaction time is a behavioral trait occurring once the target is perceived, not a visual perception trait. Thus, the inclusion of simple reaction time (SRT) in the definition of KVA as a visual trait is problematic. We hereby define KVA as the visual acuity the target indicates at only the visual trait's consciousness time ( $t_c$ ), excluding simple reaction time (SRT).

$$KVA_{old} = S(t_r) \quad (1)$$

$$KVA_{new} = S(t_c) \quad (2)$$

KVA old: Traditional KVA

KVA new: Newly defined KVA

S: Static visual acuity

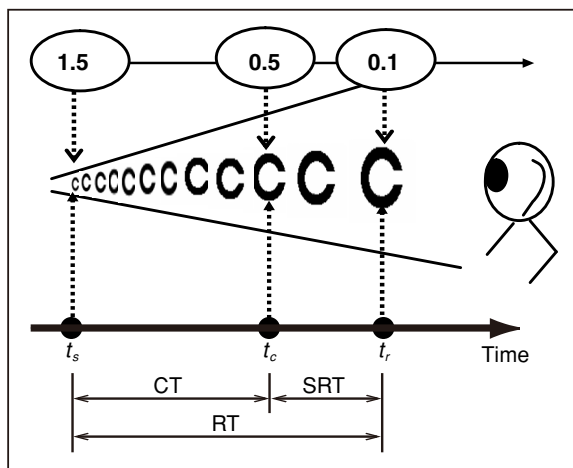


Fig. 2 Concept of new definition of kinetic visual acuity

$S(t_r)$  and  $S(t_c)$  in the formulas represent the static visual acuity indicated by the target at the  $t_r$  and  $t_c$  times, respectively. Since traditional KVA includes simple reaction times, we discovered that  $KVA_{old} \leq KVA_{new}$ .

Since  $t_c$  cannot be directly measured, the newly defined KVA new from formula (2) cannot measure kinetic visual acuity. However, since reaction time (RT) can be measured, consciousness time (CT) can be calculated according to formula (3) below if simple reaction time (SRT) is measured, and from there KVA new can be measured according to formula (4).

$$CT = RT - SRT \quad (3)$$

$$KVA_{new} = S(CT) \quad (4)$$

Employing the same new definition of kinetic visual acuity as above, we can describe a new definition of visual field range that takes into consideration individual differences in simple reaction times.

#### 4. EXPERIMENTAL EVALUATION OF THE NEWLY DEFINED KINETIC VISUAL ACUITY

In the traditional kinetic visual acuity evaluation method, visual acuity was calculated by the time it took to press the reaction button after identifying the target. The target continued to move during the time from when it was perceived to the time the reaction button was pressed. Hence, the traditional definition of kinetic visual acuity was a mixed result of visual traits and behavioral traits. Thus, strictly speaking, it was not exactly kinetic visual acuity as a perceptual function of vision. This evaluative experiment compares the results obtained between measurements that employ the traditional kinetic visual acuity definition method, and those that employ this study's newly defined method.

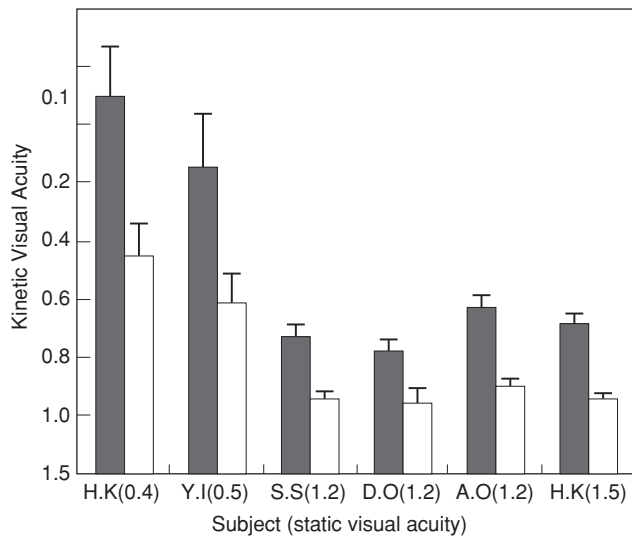
##### 4.1 Evaluative experiment system

The evaluative experiment conducted used the visual acuity test apparatus developed by the authors in past studies. Subjects are six healthy males aged 21 - 58, each with static visual acuities ranging from 0.4 - 1.5.

First, use the simple reaction time testing function to measure the subjects' simple reaction times (SRT). Next, use the kinetic visual acuity testing function to measure the traditionally defined kinetic visual acuity and the newly defined kinetic visual acuity. The measurement method involved a hiragana target moving at the speed of 30 km/h. When subjects could identify a Japanese character “あ,” they pressed the reaction button. The reaction time (RT) at that moment was recorded, along with the “あ” target's size at the RT. Using formula (1), the visual acuity corresponding to the “あ” target's size at the RT is the traditional kinetic visual acuity. Using formulas (3) and (4), the visual acuity is the newly defined kinetic visual acuity.

##### 4.2 Experiment results and considerations

Experiment results are shown in Figure 3. The graph's horizontal axis shows subject names and static visual acuities, while the horizontal axis shows kinetic visual acuity. The black and white bars indicate traditional and newly defined kinetic visual acuities, respectively. Static visual acuities for each of the subjects are 0.4, 0.5, 1.2 and 1.5. From Figure 3, we see that the results of the



**Fig. 3 Evaluative experimental results of traditional kinetic visual acuity (KVA<sub>old</sub>) and new kinetic visual acuity (KVA<sub>new</sub>)**

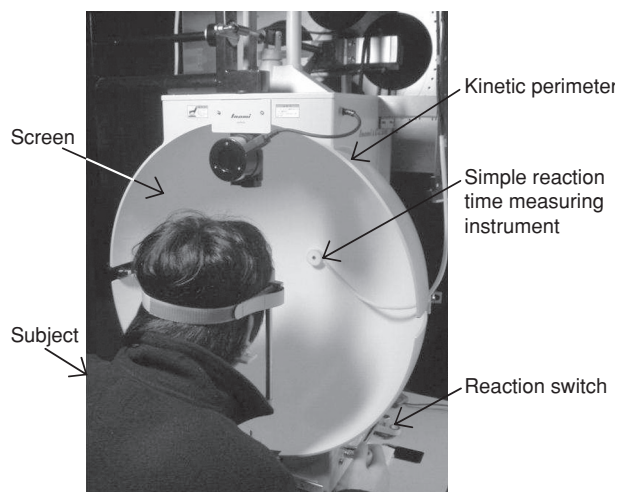
newly defined kinetic visual acuity method (white bars) were less than those of traditional kinetic visual acuity. This is because the newly defined kinetic visual acuity method calculated visual acuity without including human behavioral traits. Thus, kinetic visual acuity calculated using the newly defined method can eliminate individual differences in human behavioral traits to produce what we believe to be a more accurate evaluation indicator of human visual functions.

#### 5. CONSIDERATION OF KINETIC VISUAL FIELD AGING EFFECTS

##### 5.1 Kinetic visual field measurement method

As seen in Figure 4, the kinetic perimeter apparatus used to measure kinetic visual fields in this study employs an electric slider to replace the target movement operation of the manually operated Goldman perimeter, making it automatic. This Goldman perimeter is used to measure simple reaction times and kinetic visual fields. Specifically, a spot of light moves at a fixed rate of speed from the periphery of the visual field to its center. When the subjects see the target they press the reaction button, thereby measuring their kinetic visual fields.

Subjects are one group of young persons (ages 18 - 24: 6 people), middle-aged persons (ages 55 - 62: 6 people) and senior citizens (ages 65 - 72: 6 people, 75 - 89: 6 people), for a total of 24 people. Kinetic visual field measurements are conducted in a dark room with only the right eye, covering the subjects' left eyes with sterile gauze



**Fig. 4 Kinetic perimeter system**

so they cannot see from that eye. There are four target conditions, shown in I - IV of Table 1. The background screen is 10 (cd/m<sup>2</sup>) and white. Target meridians are in 12

**Table 1 Target conditions**

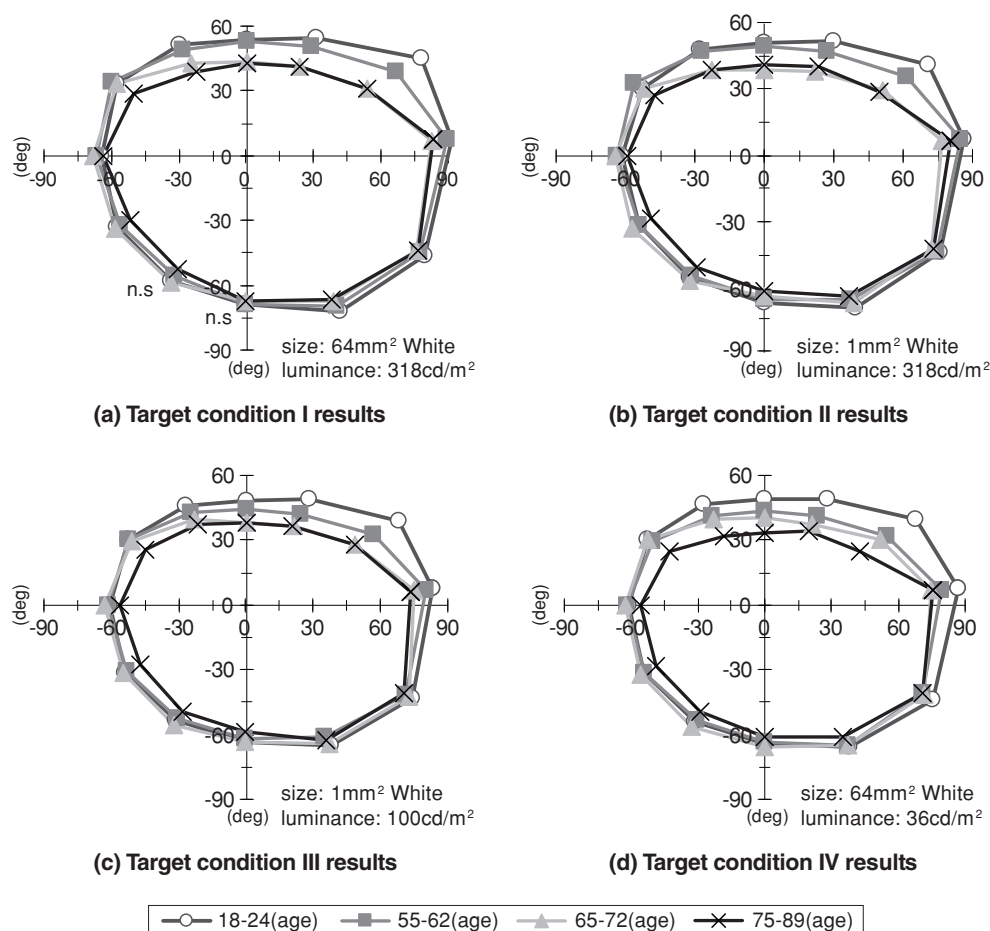
Condition number	Size (mm <sup>2</sup> )	Luminance (cd/m <sup>2</sup> )	Color
I	64	318	White
II	1	318	White
III	1	100	White
IV	64	36	White

different directions, separated at 30° angles. Take four measurements at each meridian and record the mean values.

Take measurements using the three target movement speeds of 5, 10 and 15 (deg/s) for target conditions I, II and III, and the two target movement speeds of 5 and 15 (deg/s) for target condition IV. Take four measurements for each target condition/meridian and use the mean values as results.

## 5.2 Kinetic visual field measurement results

Kinetic visual field measurements results are shown by age group in Figure 5. These were compiled by mean



**Fig. 5 Kinetic visual field experiment results by age group: Target movement speed of 5 (deg/s)**



values of angles of eccentricity, measured by each meridian. Vertical and horizontal axes show a visual angle with a fixation point of 0 (deg).

(a) - (d) in Figure 6 illustrate target conditions I - IV. The four polygonal lines in each of the graphs are the age group averages by a target movement speed of 5 (deg/s). These kinetic visual fields illustrated by each target condition are the results that reflect the individual simple reaction times of the subjects.

In the measurement results of all four target conditions, the kinetic visual field shapes decrease in size as subjects age. This decrease is minute in downward visual field angles, but quite marked in upward visual field angles.

In particular, visual field angle reduction accompanying aging is most dramatic in the temple-side upward angle of 30 (deg), while the range showing an insignificant difference in visual field angles between age groups is primarily on the meridian of the downward visual field. Note also that in regard to fluctuations of the kinetic visual field shapes due to target size and luminance, there are no great differences in visual field angles due to individual meridians.

The meridian directions are shown at angles centered on the fixation point, with the temple-side horizontal direction at 0 (deg), the counterclockwise upward vertical direction at 90 (deg), the nose side at 180 (deg), and the visual field's downward vertical direction at 270 (deg).

The greatest visual field reduction accompanying aging is at the meridian angle of 30 (deg), with as much as an approximately 30 (deg) difference between the young person age group and the 75 - 89 year-old senior citizen age group. Eccentric angles ranging from 10 to 20 (deg) are also evident in the upward visual field direction meridian angles of 5 - 150 (deg). In contrast, there is less

than a 10 (deg) difference with the young person age group's eccentric angle covering meridian angles 180 - 330 (deg), which comprise the nose-side horizontal direction and the downward visual field direction.

From the above, it can be surmised that visual field angle changes in kinetic visual field shapes accompanying aging are greatest in upward visual field directions. Contrarily, visual field angle changes accompanying aging are small in downward visual field directions. This trend was seen in all target conditions.

### 5.3 Kinetic visual field area calculation method

The kinetic visual field area is found by calculating the area inside subject isopters. The reason for this is so that the amount of the visual field seen can be quantitatively described, setting the fixation point as the eccentric angle of 0 (deg). In this study subject isopters are shown in polygons, so the area inside the polygons is calculated as the kinetic visual field area.

First we will describe the method to calculate the kinetic visual field area without taking into account the simple reaction times of subjects.

A section ( $A_i$  [deg<sup>2</sup>]) of the area of isopter A, obtained in the kinetic visual field measurement shown in Figure 6, can be determined from the two response points  $a_i$  [deg],  $b_i$  [deg] and the single fixation point O using formula (5).

$$A_i = (1/2) \times a_i \times b_i \times \sin \theta_i \quad (5)$$

Use formula 5 to determine the areas of all the sections within isopter A, and total the sums to arrive at the kinetic visual field area without taking into account simple reaction times.

Next, we will describe the method to calculate the kinetic visual field area while taking into account simple reaction times. The eccentric angle  $R$  [deg], which is the response point of isopter A obtained in the kinetic visual field measurement shown in Figure 6, is reduced by the amount of simple reaction time it took for subjects to respond after seeing the target. In other words, the eccentric angles subjects essentially have are larger than  $R$  [deg] by simple reaction time [s]  $\times$  target movement speed [deg/s] ( $=\Delta R$  [deg]). Thus, isopter A', which is the kinetic visual field taking into account simple reaction time, is determined by adding  $\Delta R$  [deg] to each of the response points in isopter A. The area of isopter A' is calculated the same way as the area for isopter A, determining the area of a section of isopter A' ( $A'_i$  [deg<sup>2</sup>]) from the two response points  $a'_i$  [deg] and  $b'_i$  [deg] and the single fixation point O.

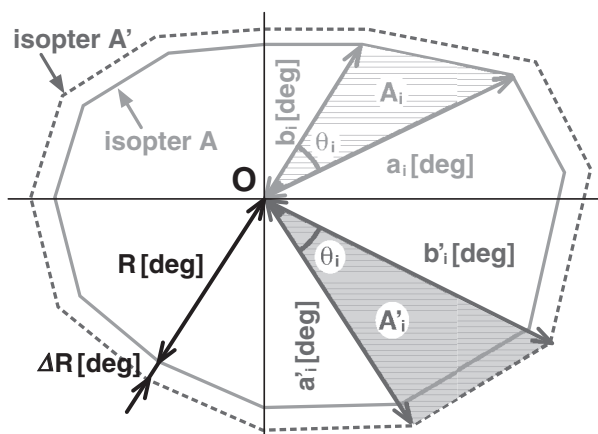


Fig. 6 Calculation method of kinetic visual field

$$A'_i = (1/2) \times a'_i \times b'_i \times \sin \theta_i \quad (6)$$

The kinetic visual field area, compensating for simple reaction times, is then reached by using formula (6) to calculate all the sections of isopter  $A'$  and adding them together.

#### 5.4 Kinetic visual field area

Age group averages of kinetic visual field areas measured by each target condition are shown in Figure 7. The vertical axis of each graph is the kinetic visual field area ( $\text{deg}^2$ ), while the horizontal axis shows the age groups.

The kinetic visual field areas shown in Figure 7 take into account the simple reaction times of the sub-

jects. Graphs (a) - (d) show the kinetic visual field areas for each age group under target conditions I - IV.

Regarding the kinetic visual fields divided by age groups, the  $t$  test, which checked for target movement speed dependence, revealed that although a significant difference in kinetic visual field areas was evinced due to target movement speed differences in all age groups in target conditions II and III, which employed small target sizes, significant differences tended to diminish. Meanwhile, in target conditions I and IV, which employed large target sizes, dependence on kinetic visual field area target movement speeds (in these measurement ranges) was low.

#### 5.5 Aging effects on kinetic visual fields

Using kinetic visual field areas that take into account the individual simple reaction times of subjects, this study investigated dependencies on target sizes, target luminance and target colors of kinetic visual field areas.

The results showed significant differences in kinetic visual field areas between target conditions I and II, and target conditions II and III, indicating a dependency on target size and target luminance in kinetic visual field areas. Results for target speeds 10 and 15 ( $\text{deg/s}$ ) showed an equivalent trend. However, in higher subject age groups, particularly the 75 - 89 year old age group, there were large kinetic visual field area differences within individual group members, reducing significant differences.

As shown in Figure 7, kinetic visual field areas diminished as subjects aged in all target conditions set in this study. This indicates a tendency for kinetic visual field areas to diminish as people age. Since a reduction of kinetic visual field areas with age occurs even when taking into consideration the simple reaction time behavioral trait when measuring kinetic visual acuity, the cause for this trend appears to be a deterioration in vision as people age.

However, as seen in Figure 5, the reduction in kinetic visual field shapes is not a uniform reduction centered on the fixation point, but rather greater reduction accompanying aging occurs in the upward visual field, particularly in the eccentric angles on the temple sides, than in the eccentric angles in the lower visual field. The marked eccentric angle decrease accompanying aging in the upward visual field of kinetic visual fields may be due to acquired factors, such as light-induced damage on the lower part of the retina is major, or due to anatomic factors, such as the fragility of the lower optic nerve fibers. Another possible reason may be because the area in which the upper eyelid shields the eye expands due to

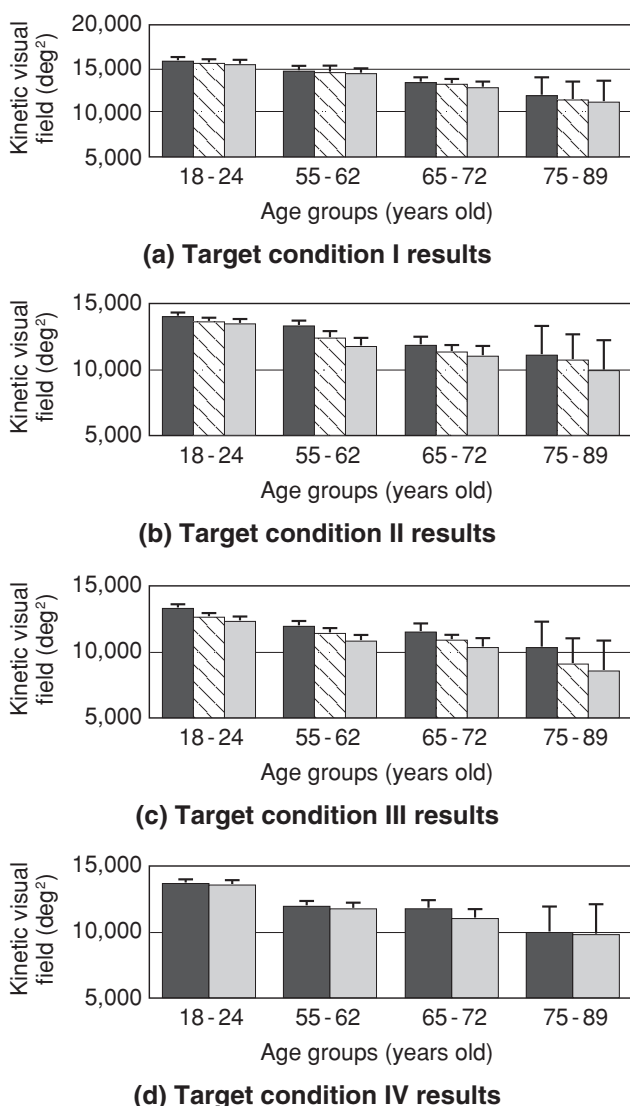


Fig. 7 Kinetic visual field averages by age group

upper lid ptosis as people age, according to a study<sup>10</sup> that finds the distance between the edge of the upper eyelid and the center of the pupil shrinks with age.

## 6. CONCLUSION

This study first identified problems with traditional kinetic visual acuity (KVA), and experimentally investigated simple reaction times and aging effects. Simple reaction tests revealed that simple reaction times are longer for senior citizens. Moreover, it redefined KVA and proposed a KVA test method that takes into account behavioral traits. The new KVA definition takes into account simple reaction time, enabling the accurate measurement of KVA. Next, the appropriateness of the new kinetic visual acuity definition was proven by results of evaluation tests of both the old and new kinetic visual acuity definitions.

The study also proposed a new method to define kinetic visual fields that, like the new definition of kinetic visual acuity, take into consideration individual differences in simple reaction times. Further, it tested young persons (ages 18 - 24: 6 people), middle-aged persons (ages 55 - 62: 6 people) and senior citizens (ages 65 - 72: 6 people, 75 - 89: 6 people) to measure the relation of target size, luminance, color and speed to kinetic visual fields, quantitatively investigating the effects aging has in kinetic visual fields. Test findings for kinetic visual acuity target movement speed dependencies were not shown due to paper length restrictions, but no kinetic visual acuity target movement speed dependencies were observed. However, a reduction in kinetic visual field area accompanying aging was observed in all conditions. Moreover, the upward visual field shrunk dramatically more than the downward visual field in all target conditions. Reduction of the temple-side upward visual field angle was particularly noteworthy.

## REFERENCES

1. Ludvigh, E. The Visibility of Moving Objects. "Science" Vol. 108, pp. 63-64 (1948).
2. Ishigaki, H. and Miyao, M. Implications for Dynamic Visual Acuity with Changes in Age and Sex. "Percept Mot Skills" Vol.77: pp. 835-839 (1993).
3. Mashimo, I. Sports Vision: Vision for Sports (2<sup>nd</sup> edition). NAP Ltd. (1997). (in Japanese).
4. Suzumura, A. Dynamic Vision Research. Nagoya University Research Institute of Environmental Medicine Report. (1962). (in Japanese).
5. Hasjimoto, S. Development of a Kinetic Visual Field Measuring Program Using an Automatic Perimeter. "Medical Journal of Kinki University" 28: pp. 207-221. (2003). (in Japanese).
6. Baba, H. Investigation of factors leading to the quantification of the Goldman visual field in normal persons. "Japanese Ophthalmological Society" 90(7): pp. 62-66. (1986). (in Japanese).
7. Wu, J., Lu, S., Hayashi, Y. Study and Development of a Visual Acuity Equipment with Multifunction for Three Subjects at Once. The Japan Society of Mechanical Engineers - Collected Papers, Group C 74-737:pp. 83-89. (2008). (in Japanese).